Overview of MSFC's Applied Fluid Dynamics Analysis Group Activities

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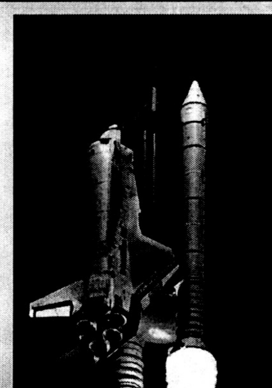
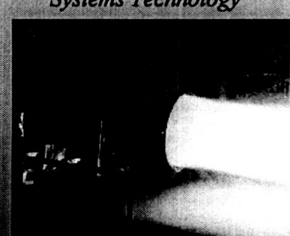
Overview

- **Introduction**
  - Fluid Mechanics at MSFC
- **Relevant Fluid Dynamics Activities at MSFC**
  - Turbomachinery
  - Nozzles
  - Combustion devices
  - Systems
  - MDA
- **Related Topics**
  - Hardware investments
  - Process improvements
- **Concluding Remarks**

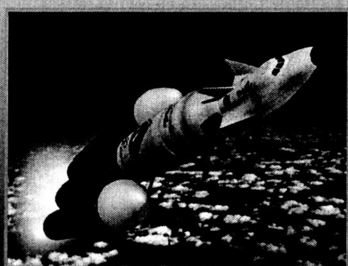


CFD on Space Transportation Systems Technology



Introduction

- **High-fidelity fluids design & analysis expertise at MSFC focused in the space transportation directorate**
  - CFD (TD64), induced environments (TD63), cold flow testing (TD62, TD63, TD74), and functional design (TD61)
- **Fluid dynamics expertise a core competency at MSFC**
- **Support focused in two broad areas**
  - Space Shuttle propulsion
  - Next Generation Launch Technologies
    - **Space launch initiative (2nd generation RLV)**
    - **Advanced Space Transportation Program (3rd generation RLV)**



Introduction: Role of Fluid Mechanics Expertise

- **Fluid mechanics applications at MSFC focused on improving the safety, reliability, & cost of space transportation systems**
- **We define geometry, quantify environments, and predict performance**
  - Incident investigation support (analysis and test)
  - Environments and performance definition (analysis and test)
  - Develop advanced hardware concepts and designs (analysis and test)
- **We support the programs in meeting their goals**
  - Assist the programs in being "smart buyers"
  - Provide innovative technical solutions
- **We work with external partners who possess key capabilities**
  - Other NASA centers, other government agencies, industry, academia

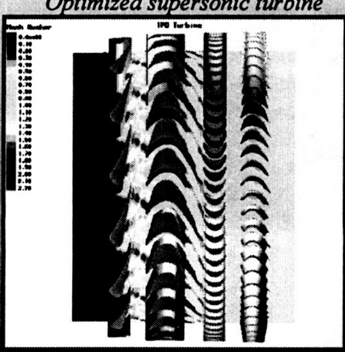
Introduction: CFD Goals

- **Provide personnel with the tools to succeed**
  - Maintain and enhance civil service personnel capabilities
  - Provide challenging work, hands-on experience, training
  - Continuously improve analysis techniques, computing resources, and test facilities
- **Acquire/develop capability to perform broad, CFD-based parametric design concept studies**
  - Spend more time engineering, less time "CFDing"
  - More efficient use of available computing resources
  - Requires automation in all phases: grid generation, flow solver, post-processing
- **Expand range of CFD applicability**
  - Improved models, combustion, transient processes, relative motion, cavitation, multi-component
  - Greater efficiency and robustness in flow solvers

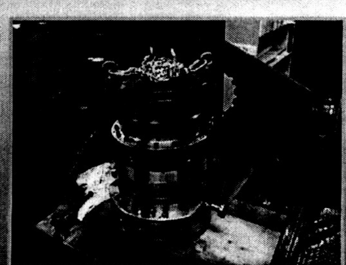
Turbomachinery Activities

- **Turbomachinery Dynamic Environments and Performance**
  - High power density of rocket engine turbomachinery requires high-fidelity definition of the flow induced environments
  - Supported in TD64 w/ CORSAIR and w/ test definition & support
- **Turbopump optimization task**
  - 2 stage supersonic turbine, instrumented rotor
  - Tool improvements, design process improvements, rig design, manufacture, and testing

Optimized supersonic turbine



Calibration of on-rotor instrumentation complete

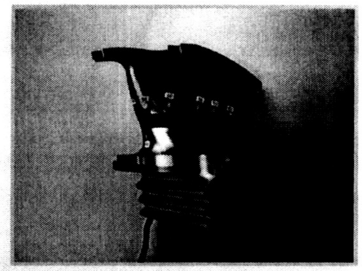


Proof-pressure test completed

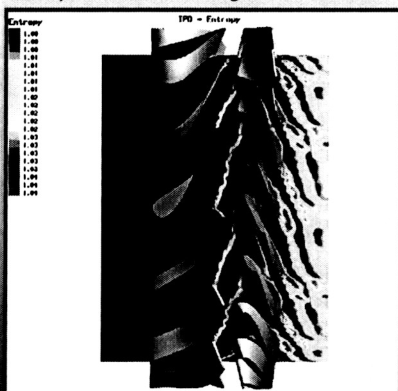
Turbomachinery Activities

SLI Turbine Airflow test rig:

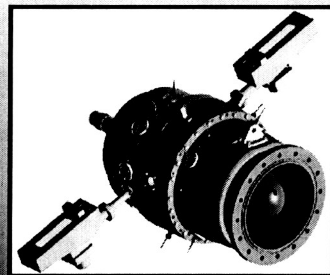
- Subsonic, high flow turbine
- Design, analysis, manufacture, testing
- Instrumented rotor for code validation
- Turbine test rig in manufacture



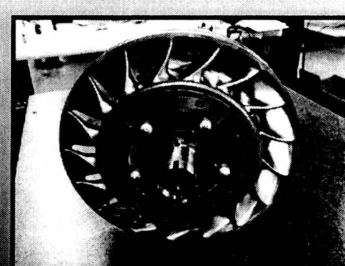
CFD analysis of tester predicts similar flow patterns as for engine conditions



Test rig mechanical design complete

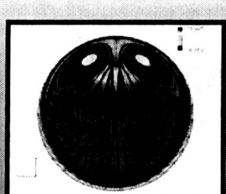


Rig parts in manufacture



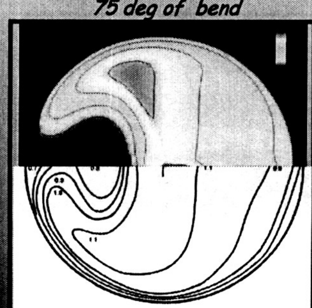
Turbomachinery Activities

- **Conducting CFD code validation to support pump-feedline design**
  - Manifolds/feedlines interaction w/ rotor is an important effect
  - Have benchmarked Corsair and Chem for pipe flows
  - Applying validated code towards optimization of feedline for candidate configuration
    - **Initial optimization w/ feedline alone**
    - **Final optimization to include coupling of feedline to rotor**

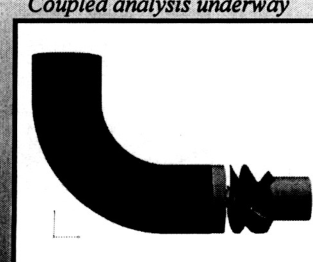


Initial 2 elbow-alone simulations complete

CFD to data comparison 75 deg of bend



Coupled analysis underway

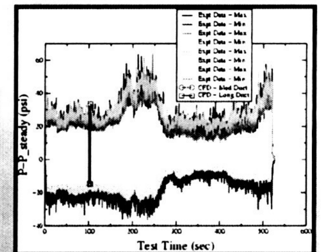


Turbomachinery Activities

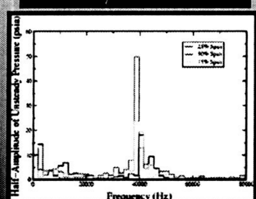
Space Transportation Directorate

NASA

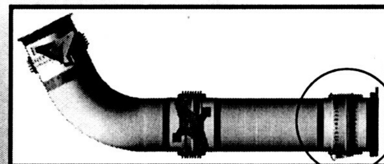
- **Space Shuttle LPOT nozzle cracking**
  - First application of Corsair to "incompressible" flow field prediction
- **Shuttle feedline flow liner cracks investigation support**
  - Predicting large p' at flow liner due to back flow from inducer
  - Circumstantial evidence supports predictions

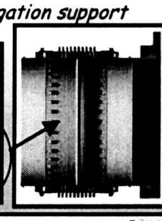


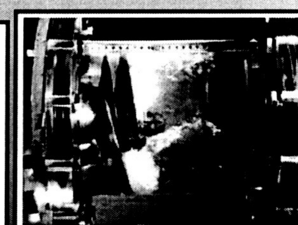
SSME LPOT vane cracking



Shuttle feedline cracking investigation support







Rotating cavitation

Axial velocity = -10 ft/sec iso-surface colored with static pressure

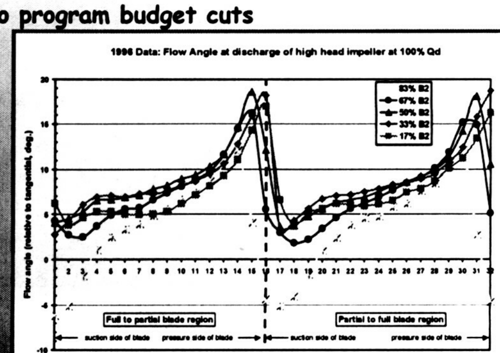
Turbomachinery Activities

Space Transportation Directorate

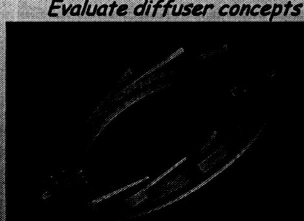
NASA

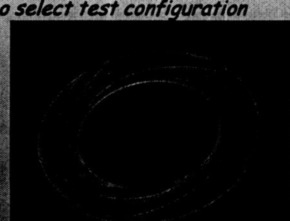
Deep Throttle Turbopump task

- Cooperative effort between Ames/MSFC/Rkdn
  - **Generate CFD validation data set for pumps**
  - **Apply validated CFD code to develop deep throttling pump design concepts**
  - **INS3D from Ames applied to SOA designs**
  - **Assess code, improve designs**
- Task back within project guidelines for FY03
  - **Task largely dormant in FY02 due to program budget cuts**



Evaluate diffuser concepts to select test configuration

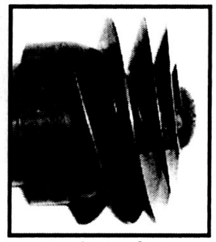




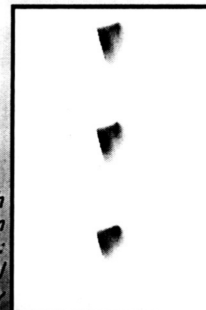
Example of LDV data from water flow testing

Turbomachinery Activities

- **Concepts NREC Inducer design Phase 2 SBIR**
  - Develop engineering design tools for cavitating inducers
  - Verify through new inducer designs
- **CRAFTech Cavitation Analysis Capability Development Phase 2 SBIR**
  - Extend current model to cryogenic propellants
  - Add time accurate capability in cavitation model
- **Developing Phantom to better support unsteady turbomachinery analysis**
  - Uses much of Corsair infrastructure
  - New formulation will support real fluids model
    - **Improved efficiency for solving pump problems**
    - **2-phase flows, non ideal fluids, etc.**



Inducer from Concepts NREC SBIR

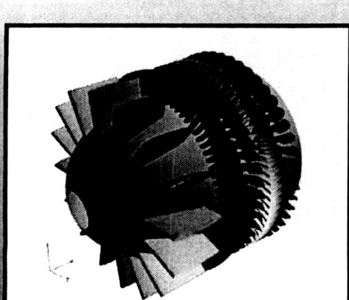


CRAFTech cavitation modeling: established initial capability

Turbomachinery Activities

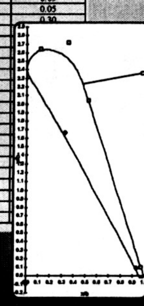
- **Supported Cobra Turbine designs**
  - PW/AJ joint venture staged combustion LOX-H2 engine
  - Performed CFD of main turbines in various environments
    - **full 360-degree analysis**
  - Supported design of low pressure turbomachinery
  - Airflow test rigs designed

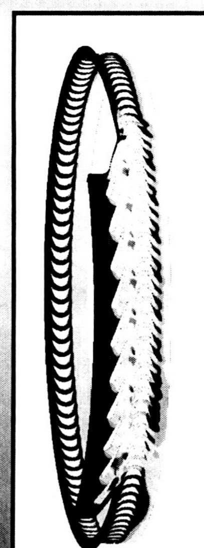
ATD High Pressure Turbines under Cobra Conditions



CFD based design parametrics

Case	H/L	Uncovered Turning	L1	L3F
Vane 0	1.35	14.0	0.11	0.20
Vane 1	1.34	15.0	0.1	0.18
Vane 2	1.28	12.0	0.05	0.05
Vane 3	1.40	12.0	0.05	0.05
Vane 4	1.28	18.0	0.05	0.05
Vane5	1.40	18.0	0.05	0.05
Vane 6	1.28	12.0	0.15	0.05
Vane7	1.40	12.0	0.15	0.05
Vane 8	1.28	18.0	0.15	0.05
Vane 9	1.40	18.0	0.15	0.05
Vane 10	1.28	12.0	0.05	0.30
Vane 11	1.40	12.0	0.05	
Vane 12	1.28	18.0	0.05	
Vane 13	1.40	18.0	0.05	
Vane 14	1.28	12.0	0.15	
Vane 15	1.40	12.0	0.15	
Vane 16	1.28	18.0	0.15	
Vane 17	1.40	18.0	0.15	
Vane 18	1.20	15.0	0.10	
Vane 19	1.47	15.0	0.10	
Vane 20	1.34	8.72	0.10	
Vane 21	1.34	25.0	0.10	
Vane 22	1.34	15.0	0.41	
Vane 23	1.34	15.0	0.18	
Vane 24	1.34	15.0	0.10	
Vane 25	1.34	15.0	0.10	
Vane 26	1.36	15.0	0.07	
Vane 27	1.36	18.0	0.05	
Vane 28	1.40	15.0	0.10	





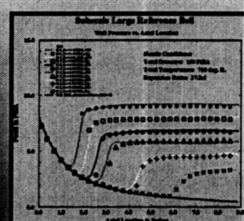
Partial admission, full annulus calculations, Variable GAMMA, w/tip shroud flow

Nozzle Activities

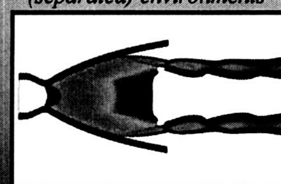
- **Technology need**
  - Nozzles are a key component in setting the engines performance, thrust to weight, and operational life limitations
  - Application of CFD tools to advanced nozzle designs immature
- **Recent/Ongoing activities**
  - Have completed initial interaction with European community via NATO RTO Working Group #10
  - Testing of Aerojet designed altitude compensating nozzles complete
    - **Full-flowing and separated CFD code validation data sets**
    - **FDNS comparisons look very good, but painful to obtain**
    - **Chem validation to follow**

4 ACN concepts
2 reference nozzles

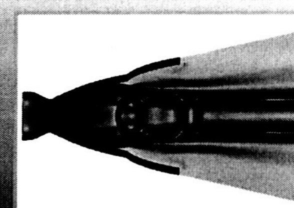
FDNS benchmark



Nozzle transient (separated) environments



Nozzle mode transition



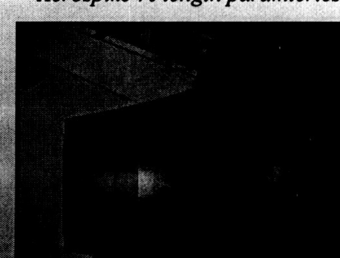
Nozzle Activities

- **Recent/Ongoing activities (continued)**
  - Tested dual-throat linear aerospike (Rkdn design concept)
    - **Highly instrumented**
  - Setting up to test annular aerospike
    - **Validation data for aerospike undergoing differential throttling for TVC**

Annular aerospike test rig,
Base bleed parametrics

Extensive p-instrumentation
Segmented thruster chambers

Aerospike % length paramterics



Combustion Devices

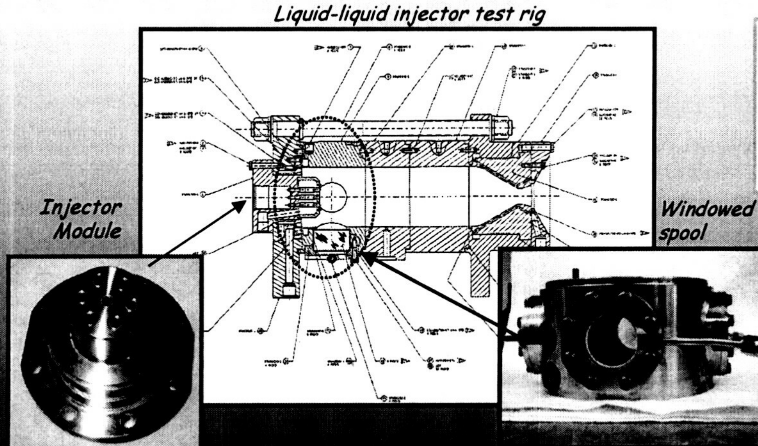
- **Technology need**
  - Contemporary rocket engine combustion devices similar to 1960s-1970s designs
  - Longer life (robust), higher T/W designs required
    - **Experimental demonstration of design robustness/life is cost prohibitive**
  - Application of CFD in design of combustion devices hampered by real limitations
    - **Inadequate accuracy (lack of physical modeling)**
    - **Inadequate turn-around time**
    - **Inadequate validation and verification where required physics are included in the CFD tools**
  - Current focus at MSFC is in rocket chamber combustion
    - **High pressure, all-speed, reacting flows**
  - Presentations Wednesday morning
  - Combustion devices technology roadmap meeting and discussion Thursday morning

Combustion Devices

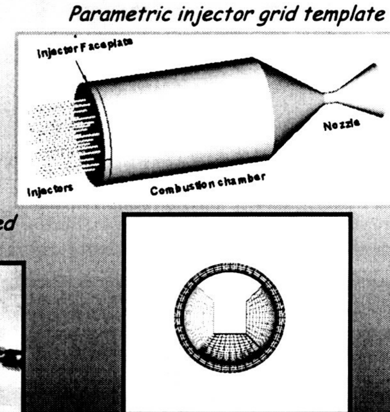
- **Focus of groups combustion devices activities is the staged combustion injector technology (SCIT) task**
  - Task objective is to develop, validate, and verify a CFD based injector design process
  - Develop 1D injector design/engineering tool
  - Develop optimization tools to allow efficient use of large number of CFD solutions
  - Develop required CFD capabilities for supporting large design parametrics
    - **Robustness, physical models, turnaround time**
  - Generate validation data sets
    - **Verify by testing injector designed using new process**
    - **Gas-gas, liquid-gas, liquid-liquid**
    - **H_2-O_2, HC-O_2**
  - Large task with ambitious goals, progress hampered by:
    - **Changes in external priorities, direction**
    - **Greater than anticipated difficulty in achieving required robust (fire-and-forget) capability in FDNS for injector analysis**
    - **Difficulty in getting data suitable for code validation**

- **SCIT task (continued)**
  - Have performed several gas-gas injectors design parametric studies
    - **Each on the order of 50 designs**
  - Have tested initial gas-gas elements at PSU (code validation)
  - Liquid-liquid injector test rig in manufacturing
  - Multi-element grid template, porosity models being tested

Liquid-liquid injector test rig



Parametric injector grid template



Combustion Devices: Injectors and Chambers

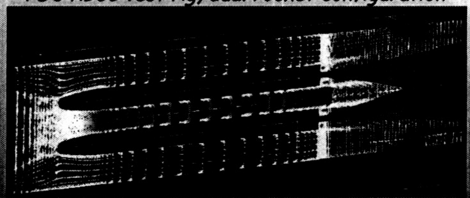
- **Several key areas are likely to get increased attention**
  - Hydrocarbon analysis capability improvement (turn-around time)
    - **Enhancement to testing at SSC of RS-84 hardware**
    - **Test data for code validation**
    - **Assessment of advanced concepts**
  - Transient modeling capability
    - **Many combustion devices related failures occur during engine transients**
    - **CFD turnaround time, sub-critical combustion, lack of validation data**
  - Combustion Stability
    - **The elephant in the room that everyone tries to avoid/pretend it's not there**
    - **Potential focused NGLT area of focus**
    - **AFRL potential new initiative**

Engine Systems

- **Technology need**
  - T/W of rocket engines sensitive to design of engine manifolds/ducts
  - Many design shortcomings traceable to interaction between components and engine "plumbing"
  - Combined cycle concepts required integrated design/analysis approach
- **Recent/Ongoing activities**
  - Internal assessment of LOCI/Chem from MSU
    - **Unstructured, density based code**
    - **LOCI architecture designed for MDA**
    - **Under NASA sponsorship for RBCC flow path application**
  - Has been applied to engine powerhead problem
  - Will be used to model RBCC flow path

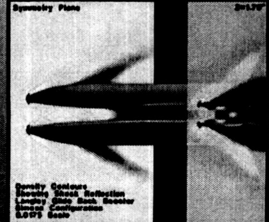
SLI engines hot-gas manifolds

PSU RBCC test rig, dual rocket configuration

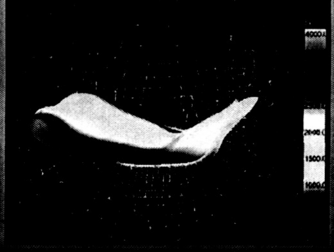


Propulsion-Vehicle System Integration

- **Technology need**
  - SOA vehicle concepts require a high level of propulsion-to-airframe integration
    - **Air-breathers (RBCC or TBCC), parallel-burn multi-stages**
- **Recent/Ongoing Activities**
  - Developing stage separation database and tools
    - **Use generic but relevant vehicle configuration to develop test database**
    - **Test effort at MSFC, CFD (w/Overflow) at JSC have been great success**
  - Further activities under SLI waiting program assessment relative to vehicle development
    - **CART3D (Ames) possible efficient way to support concept development**
    - **Chem w/automated grid templates being developed in U.F. URETI**



Stage separation data base and CFD methodology

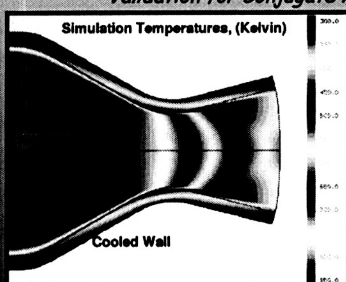


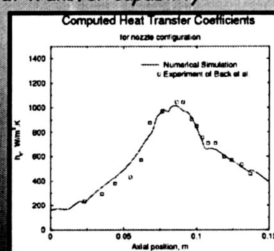
Vehicle-propulsion integration w/Chem

MDA Development

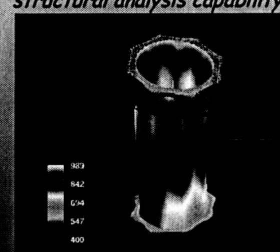
- **Technology need**
  - Many space transportation system propulsion system failures are multi-disciplinary in nature
    - **Thermally induced, fluid-structure interaction, etc.**
    - **Many are also related to transient or time varying, 3D events**
- **Recent/Ongoing activities**
  - LOCI framework being developed to support 3D, time accurate, MDA analysis capability
  - Initial demonstrations of fluid-thermal- structural modeling capability demonstrated
    - **Under URETI plan to continue development of this capability**

Validation for Conjugate heat transfer capability





Demonstration of basic fluids-thermal-structural analysis capability



CFD Process Improvements

- **Tendency towards greater CFD based design parametrics**
- **Enabled by access to traditional and non-traditional "super-computers"**
  - Access to NASA-Ames SGI based compute clusters
    - **512 and 1024 processor SGI high-end computers**
  - Two local PC-based clusters
  - Local SGI O-2000 systems
  - SGI O-2000 desktop workstations

Computers	processors	processor speed	ram
Nexus	16	250 MHz, R10k	12 GB
Korben	8	300 MHz, R12k	8 GB
Neo	16	500 MHz, R14k	16 GB
Hydra	40	600 Mhz - 933 Mhz PIII	10 GB
Chimaera	200	1500 MHz, Athlon MP	100 GB
Tyrell	32	250 MHz, R10k	32 GB
Desktops	2	400 MHz, R12k	.5 - 2 GB

CFD Process Improvements

- **Tendency towards greater CFD based design parametrics**
- **Enabled by labor-reducing utilities**
  - Improved process efficiency
  - Automatic or near automatic grid generation system
  - "fire-and-forget" flow solver capability
    - **Time-stepping, grid adaptation/refinement, multi-gridding, etc**
- **Dedicated personnel for internal process improvement**
  - Create or improved labor reducing utilities for CFD process
  - Develop visualization technology for pre- and post-processing
  - Created automated test suite for software upgrades testing
    - **Testing/validation key to robustness, improvements, reliability**
    - **Must be made affordable**
- **Continuous process**

Concluding Remarks

- **TD64 focused on supporting the space transportation programs**
  - Engaged in the Next Generation Launch Technologies program, SSME program, IR&D
- **Design and analysis tools being applied and/or under development in the major hardware areas**
  - Turbines, pumps, combustion devices, engine systems, propulsion-to-airframe integration
  - MDA capabilities under development
- **Increasing the design process efficiency and fidelity is paramount**
  - Attempting to address key shortcomings in CFD process
- **Code validation, robustness, reliability key to meeting CFD's promise**